HOT WATER TO CONTROL CODLING MOTH IN SWEET CHERRIES: EFFICACY AND QUALITY

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ABSTRACT

Quarantine regulations require domestic cherries exported to Japan be treated to control for codling moth, Cydia pomonella *(L.) (Lepidoptera: Tortricidae). The current procedure, methyl bromide fumigation, uses a restricted chemical, reduces fruit quality, and involves health, safety and environmental concerns. Single and double hot water dips were evaluated using fresh 'Bing' and 'Sweetheart' sweet cherries from Washington state as a potential replacement. The double dip procedure had a pretreatment bath at 40C for 5 min. For both procedures, submersions in heated water from 48 to 55C for 2–14 min were examined for treatment efficacy against third-instar codling moth and fruit quality. Although a 100% mortality response was found for each temperature and procedure, the submersion durations significantly*

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damaged fruit and stem parameters for both cultivars. Thus, hot water dips are not feasible for Pacific Northwest cherries at this time.

INTRODUCTION

Quarantine regulations require that, prior to export, sweet cherries must be fumigated with methyl bromide (MeBr). MeBr has long been used as a fumigant to disinfect agricultural commodities, particularly sweet cherries, with good success (Drake *et al.* 1991; Drake *et al.* 1994; Hansen *et al.* 2000). A major disadvantage in the use of MeBr is that the extended duration of exposure and temperature required to eliminate all living states of potential insect pests has led to fruit injury. However, at present MeBr is currently the only acceptable method of disinfestation. But, the future of MeBr is uncertain because of environmental health concerns and international agreements restrict the production and use of this product (UNEP 1992). To continue to export sweet cherries and other agricultural commodities, alternatives to MeBr must be determined.

Alternatives to MeBr have been proposed, particularly other fumigants, irradiation, microwave energy, temperature and atmosphere manipulation. Identification of an alternate fumigant has not received much attention due to the desire to reduce the use of agriculture chemicals. Irradiation has been considered as an alternative to MeBr and research (Drake *et al.* 1994; Miller *et al.* 1994; Drake and Neven 1997, 1998) has indicated that elimination of the insect in question, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), can be achieved with little or no fruit quality loss, but public acceptance is questionable. Microwave energy has been suggested (Ikediala *et al.* 1999) as an alternative to MeBr, but treatment uniformity and fruit quality may be a dilemma. Use of heat and cold temperatures has been suggested as an alternative quarantine treatment and both have shown possibilities (Neven 1994, 1998; Neven *et al.* 2000). Changes in the atmosphere (oxygen depletion, carbon dioxide enhancement) have been noted to affect insect survival (Sonderstrom *et al.* 1990). Using both temperature and controlled atmosphere, exposure time can be reduced and the insect can be eliminated with minimal fruit quality loss (Neven and Mitcham 1996; Shellie *et al.* 1997, 2001). Additional research (Neven and Drake 2000) determined that fruit quality problems may exist with temperature, or a combination of temperature and atmosphere. Use of hot water has also been suggested as an alternative to MeBr and some success has been reported (Feng *et al.* 2004), but shelf-life after treatment was severely limited (5 days). An acceptable, inexpensive alternative to MeBr is still a question and must be determined if exports of agricultural commodities are to continue. This research was conducted to determine the feasibility of single or double hot water bath as an acceptable quarantine treatment for sweet cherries.

MATERIALS AND METHODS

Equipment

Water was heated by a 151-L Vangard Model #6E727 (Rheem Mfg. Co., Montgomery, AL) water heater with one-phase electrical connection at 240 v and a maximum of 4500 W. A microprocessor controlled the water temperature. A Bell & Gossett (Morton Grove, IL) Model NRF-22 circulator (115 v, 60 Hz) moved the water to the holding tank from the water heater and back through 2.5-cm diameter black vinyl tubing. The oblong (94 cm long × 74 cm wide × 58 cm high) holding tank was composed of preformed fiberglass, wrapped with an aluminum coated fiberglass sheet to provide additional insulation. The hydrocooling tank was made from a low density polyethylene 38-L Rubbermaid (Rubbermaid Home Prod., Wooster, OH) bin (61 cm long × 41 cm wide × 23 cm).

Temperatures were measured using Omega (Stamford, CT) nine-count, three-wire 0.00385 α platinum 100 Ω RTD probes; the Model HYP4-16-1.5-100-EU-48-RP was used to measure internal fruit temperatures and the Model RTD-810 was used to measure bath temperature. Temperature data were collected using a data acquisition board (Measurement Computing, Middleboro, MA) composed of a CIO-EXP-RTD expansion board and a CIO-DA5802/16 ISA board with an Instacal (Measurement Computing, Middleboro, MA) v. 5, 12 amp board driver. A locally written Visual Basic 6 (Microsoft Corporation, Redmond, WA) application program directed the data to specific text files, which were later exported to Quattro Pro (Corel Corp., Ottawa, Ont., Canada) v.7 spreadsheets for storage, graphics and analysis.

Fruit Infestation

Codling moth larvae were obtained from the colony reared at the USDA, ARS-YARL Wapato, WA laboratory, where they were maintained on a soy-wheat germ-starch artificial diet at ~27C, 40–58% relative humidity, with a 16:8 h light:dark photoperiod (Toba and Howell 1991). Third instars were used to infest fruits, which is the required stage in previous quarantine tests of codling moth on cherries exported to Japan (Hansen *et al.* 2000). Immature 'Bing' cherries (average size: 12.0 Row, 6.3 g) were obtained, from the ARS Moxee Farm in Washington state, with no history of insecticide application. Each of the 50 infested fruits per treatment replicate was infested with a larva,

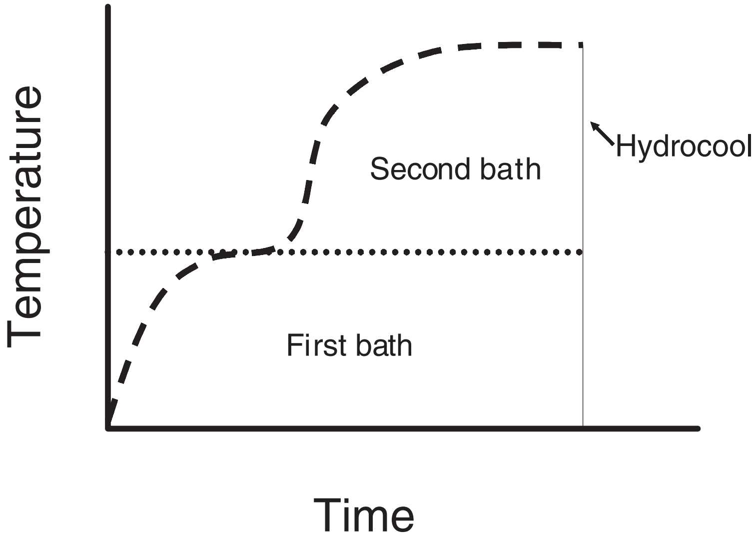

FIG. 1. TYPICAL TEMPERATURE PROFILE OF FRUIT PULP WHEN SUBMERSED IN A PRETREATMENT BATH FOLLOWED BY A TREATMENT BATH (DOUBLE-BATH PROCEDURE)

then allowed to penetrate the fruits overnight under room temperature (25C). In preparation for treatment, the cherries were placed in a fiberglass mesh bag (made of standard window screen) and the opening sealed with medium-sized paper clips. The infested fruits were treated directly out of the rearing room and treatment evaluation was conducted the day following treatment. Control infested fruits were not treated in water, but held near room temperature 20C for the duration of the treatment.

Efficacy Treatments (Insects)

Efficacy was determined at the USDA, ARS-YARL facility in Wapato, WA. Two procedures were evaluated. In the first, all fruits were submerged in a 40C pretreatment bath in order to reduce the deleterious effects of the warmer treatment bath (Fig. 1). For both procedures, fruits were subjected to different time and temperature combinations from 46 to 58C for 0.25–18 min (Table 1). Chlorine (50 ppm sodium hypochlorite) was added to both baths and the level checked before each treatment. After hydrocooling in a 4C ice water bath, the treated fruits were returned to a 25C holding room overnight, then dissected the following day to determine larval survival. As was done in other treatment tests (Hansen *et al.* 2000), moribund larvae were placed on immature

TABLE 1.
QUALITY FACTORS OF 'SWEETHEART' CHERRIES 5 AND 14 DAYS AFTER SUBJECTED TO HOT WATER TREATMENTS TO CONTROL CODLING MOTH LARVAE

Obs. day	Treatment		Fruit values			Stem value			Firm	SSC	TA	Pit	Bruise
	Temp. (C)	Time (min)	*L*	Hue	Visual	*L*	Hue	Visual					
5	25	0†	22.35	14.19	2.42	28.54	103.01	1.57	5.30	21.85	0.92	2.28	1.35
5	48	10	22.45	21.70*	2.90	27.52	98.72*	1.77	4.82	21.75	0.84**	2.75	1.62
5	50	6	21.89	15.80	2.35	27.14	97.67*	1.87	4.62**	21.02	0.86*	2.20	1.50*
5	52	2	23.34	11.64*	2.00	28.60	103.21	2.12*	5.04	21.70	0.88	1.93	1.68*
5	54	1	24.28	14.83	2.05	29.12	101.92	2.07**	5.06	21.53	0.87*	2.37	1.75*
14	25	0†	23.10	11.88	1.89	28.68	101.44	1.33	5.98	21.44	0.80	8.72	3.11
14	48	10	24.47*	13.13	2.50*	26.60	94.38**	2.17**	5.28	21.59	0.72	8.28	3.11
14	50	6	24.15*	14.16	2.78**	25.98	91.28**	2.50**	5.33*	21.81	0.75	12.17	4.78
14	52	2	23.49	11.37	2.50*	24.67*	88.39**	2.00**	5.52	21.65	0.87	2.50	2.58
14	54	1	24.71*	14.21	2.75*	25.27*	89.85**	2.00**	5.46	21.03	0.86	2.50	2.75

Significant differences from control on day of observation by Student's *t*-test: * $P < 0.05$, ** $P < 0.01$.
† Control.
Obs., observation; Temp., temperature; SSC, soluble solids content; TA, titratable acidity.

organic apples and inspected periodically until they died or pupated. During evaluation, missing larvae were considered dead.

Fruit Quality

Sweet cherries ('Bing,' 'Lapins,' 'Rainier' and 'Sweetheart') used in this study were harvested at commercial maturity, using fruit from individual trees (3) as replication. Cherries were transported, without cooling, directly to the USDA, ARS-TFRL, Wenatchee, WA and treated the day harvested. Prior to hot water treatment, cherries from each cultivar and replication were divided into groups of 1 kg. During the first year of the study cherries were exposed to 15 temperature and time combinations (46C at 14, 16, 18 min; 48C at 12, 16, 18 min; 50C at 10, 12, 14 min; 52C at 6, 8, 10 min; 54C at 2, 4, 6 min). During the second year cherries were exposed to 14 treatment combinations (48C at 4, 6, 10, 12 min; 50C at 4, 6, 8, 10, 12 min; 52C at 6, 8, 10 min; 54C at 4, 6, 8 min). During the third year of the study 11 treatment combinations (48C at 10, 12, 16 min; 50C at 6, 10, 12 min; 52C at 2, 5, 7 min; 54C at 3, 6 min).

Water was heated with a 151-L Vangard, model 6E727 (Rheem Mfg., Montgomery, AL) water heater with a one-phase electrical connection at 240 v with a maximum of 4500 W. A microprocessor controlled water temperature. A Bell & Gossett (Morton Grove, IL), model NRF-22 circulator (115 v, 60 Hz) moved the water to the holding tank from the water heater and back. The 50-gal treatment tank was composed of preformed fiberglass (Rubbermaid Home Prod., Wooster, OH). After hot water treatment the cherries were immersed in ice water, containing 50 ppm sodium hypo-chlorite, until an internal temperature of 5C or less. Cherry temperatures were monitored before, during, after hot water treatment and after cooling using a thermocouple thermometer, model 600-1040 (Barnant Co., Barrington, IL).

Cherry quality was evaluated after 5 and 14 days of storage. Quality evaluation consisted of objective and subjective color, firmness, soluble solids content (SSC), titratable acidity (TA) and evaluation for defects (visible burn, rots, internal breakdown). Objective color of the fruit and stems was determined with a colorimeter (ColorFlex, model 45/0, Hunter Assoc., Reston, VA) using the L^*, a^*, b^* system and calculated hue values (Hunter and Harold 1987). Firmness was determined using the Universal TA-XT2 texture analyzer (Texture Technologies, Scarsdale, NY) equipped with a 3-mm probe with a penetration distance after contact of 7 mm and values were expressed in Newtons (N). SSC of the fruit were determined with an Abbe-type refractometer with a sucrose scale calibrated at 20C. Acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as percentage of malic acid. Visual defects of the fruit (burn, pitting, bruising, rot, internal breakdown) and stem (burn) was evaluated by laboratory personnel and reported as percent of the total.

Subjective quality (color) of both fruit and stem was evaluated by the same laboratory personnel and graded on a scale of 1–4 (1 = excellent, 2 = good, 3 = fair, 4 = poor). Fruit or stems receiving subjective scores >2.5 were considered unacceptable.

Data Analysis

Temperature and survival data were entered into Quattro Pro v. 7 spreadsheets (Corel Corp. Ltd, Ottawa, Ont., Canada). Internal temperatures were illustrated by using the graphics program in Quattro Pro and univariate statistics were calculated by using the appropriate Quattro Pro function statements. Regression tests were completed using TableCurve2D, v. 5 (SYSTAT Software Inc., Richmond, CA). Analysis of variance and Student's *t*-tests were conducted on the fruit quality parameter data by using the general linear model procedure (SAS Institute, Cary, NC).

RESULTS

Efficacy

Larval mortality was directly related to bath temperature and duration (Figs. 2 and 3). Our experiments show a clear transition among the treatments from a few survivors to those with no survivors. The time of exposure to demonstrate no treatment survival decreased with increased bath temperatures and produced a linear fit where $r^2 = 0.767$, $a = 66.46$ and $\beta = 1.13$. In the double-bath procedure, the minimum time of exposure for each treatment needed to produce no survivors was expressed ($r = 0.986$) by the equation:

$$Y = (793.4 + 14.2x)^{1/2}$$

where x is the bath temperature in C and y is the bath duration in minutes. The pretreatment bath was assumed not to contribute lethal effect because of its lower temperature (Wang *et al.* 2002; Hansen *et al.* 2004).

Fruit Quality

Exposure of 'Bing' sweet cherries to the single hot water bath resulted in extreme loss of fruit quality, regardless of temperature or time of exposure (Table 2). Immediately after treatment (data not shown) quality differences among treatments were not evident, but after only 5 days of storage (1C) quality loss was very evident and after 14 days of storage quality loss was extreme. Objective fruit color values (L and hue) were not influenced by hot

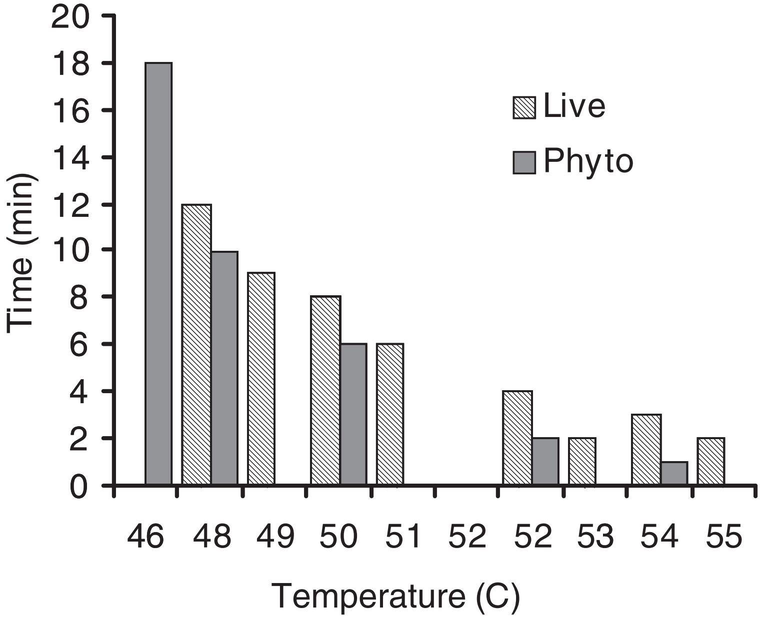

FIG. 2. TEMPERATURE DURATION OF HOT WATER BATHS USED FOR CONTROLLING FIFTH-INSTAR CODLING MOTH LARVAE IN APPLES
'Live,' maximum times that resulted in larval survivors; 'Phyto,' times used for phytotoxicity evaluations.

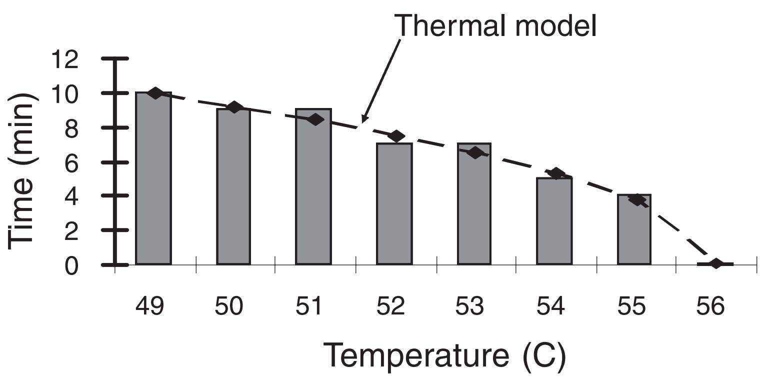

FIG. 3. MINIMUM TIME-TEMPERATURE EXPOSURES TO OBTAIN 100% MORTALITY IN HOT WATER-TREATED CHERRIES INFESTED WITH THIRD-INSTAR CODLING MOTH AFTER A 5-min PRETREATMENT AT 40C AND THE DESCRIPTIVE LETHALITY MODEL, $y = (793.4 + 14.2x)^{1/2}$, WHERE y IS TIME IN MINUTES AND x IS TEMPERATURE IN C

TABLE 2.
MEAN QUALITY FACTORS OF 'BING' CHERRIES 5 AND 14 DAYS AFTER SUBJECTED TO HOT WATER TREATMENTS TO CONTROL CODLING MOTH LARVAE

Obs. day	Treatment		Fruit values			Stem value			Firm	SSC	TA	Pit	Bruise
	Temp. (C)	Time (min)	*L*	Hue	Visual	*L*	Hue	Visual					
5	25	0†	24.96	13.88	1.10	36.36	103.22	1.75	7.90	23.42	0.96	1.15	1.20
5	48	10	24.41	12.87	1.92**	23.89*	86.55	2.00	6.46*	23.53	0.82**	1.58	1.67
5	50	6	25.08	11.05	1.83**	21.32**	79.51*	2.00	6.28*	22.47*	0.73**	1.67*	1.42
5	52	2	24.07	11.05	2.03**	23.22*	83.12*	2.25	7.54	23.65	0.92	1.52	1.10
5	54	1	24.93	11.68	2.00**	22.33**	78.96*	2.25*	7.41	22.85	0.89*	1.75**	1.10
14	25	0†	23.07	13.58	1.67	26.91	91.12	1.72	8.21	21.78	0.81	2.19	1.73
14	48	10	22.88	16.82	2.25*	22.51*	70.85	2.58**	6.73*	22.28	0.72	2.33	2.33
14	50	6	24.17	16.57	2.52**	18.81**	63.31**	3.50**	7.08	22.02	0.67	2.67	2.37
14	52	2	22.24	17.25	2.38**	18.34**	60.12**	2.75**	7.49	22.98	0.86	2.17	2.17
14	54	1	22.18	18.53	3.12**	19.12**	61.44**	3.57**	8.00	22.72	0.87	2.75**	2.75

Significant differences from control on day of observation as determined by Student's *t*-test: * $P < 0.05$, ** $P < 0.01$.
† Control.
Obs., observation; Temp., temperature; SSC, soluble solids content; TA, titratable acidity.

water treatment, but visual fruit color/condition was significantly reduced, after only 5 days of storage, for all fruit treated with hot water. Visual values for fruit treated with hot water at 52 and 54C were in excessive of acceptable levels (<2.0) even after only 5 days of storage. After 14 days of storage visual fruit color/condition differences were very convincing, regardless of temperature or time of exposure, all treated fruit displayed values for fruit color/condition in excess of acceptable (<2.0) levels and when exposed to hot water at 54C were scored at >3.0. Control fruit displayed acceptable values (1.7) for fruit color/condition even after 14 days of storage. Lower exposure times, regardless of temperature, had less influence on fruit color both objective and visual. Both objective and visual stem color were reduced when fruit with the stem was exposed to hot water regardless of the temperature or time. Stems exposed to hot water were brown in color and very unacceptable even after only 5 days of storage. All treated fruit, at 5 days, displayed stem values at 2.0 or greater. After 14 days of storage, all treated fruit stems were graded >2.5, a very unacceptable value. As temperature was increased both objective and visual stem color was reduced. Fruit quality is often determined on the condition of the stem and stem color is often used to assess fruit quality. At all temperatures and times of exposure visual stem color was reduced when compared with stems from control fruit. This stem quality difference between treated and nontreated fruit was evident after only 5 days of storage and more so after 14 days of storage.

Firmness loss for hot water-treated ‘Bing’ cherries occurred only when the exposure time was 6 min or longer. No firmness loss was evident when cherries were exposed to temperatures of 52C or greater and much shorter exposure times of 1–2 min. ‘Bing’ cherries developed increased pitting when exposed to hot water treatment. Pitting was not evident after 5 days of storage, except when fruit was exposed to 54C for 1 min; after 14 days of storage all fruit exposed to hot water treatments displayed excessive pitting. This pitting problem, aggravated by hot water treatments, was to the extent that a USDA grade decrease would be assured. SSC and amount of decay present were not influenced by hot water treatment. TA was influenced by some hot water treatments, but no distinct pattern, after either 5 or 14 days of storage, was evident. The amount of bruising present was similar between control and treated fruit regardless of storage time.

Exposure of ‘Sweetheart’ cherries to hot water treatment to meet quarantine requirements also resulted in extreme quality loss (Table 1). Fruit color values (*L* and hue) were influenced to some extent by hot water treatment, but no apparent pattern of quality loss was evident, except for *L*-values after 14 days of storage. These *L* color values were elevated for cherries from all hot water treatments, except for 52C for 2 min. No change in *L*-values was present for cherries treated at 52C for 2 min compared with *L*-values for control fruit. After

5 days of storage, visual evaluation of fruit color/condition was the same between control and treated fruit, and all were graded in excess of an acceptable ($<$2.0) level. After 14 days of storage, control fruit displayed visual score (1.9), but barely. All treated fruit received scores for fruit color/condition of 2.5 or higher, a very unacceptable level. Stem color values (*L* and hue) were much reduced with hot water treatment, particularly after 14 days of storage. After 5 days of storage, hue values were reduced for fruit treated at 48 and 50C with long exposure times. These changes in *L* and hue values would indicate a darker-colored stem and visual evaluations for stem color/condition agree completely with hue values. After 5 days of storage, only stems treated at 52 and 54C received scores that were unacceptable (greater than 2.0). After 14 days of storage, stems of all treated fruit were graded ($>$2.0) at unacceptable levels. Stems from control fruit were acceptable after 5 and 14 days of storage.

Hot water treatment of cherries to meet quarantine requirements had little or no effect on fruit firmness, SSC, TA, pitting or bruising (Table 1). At some temperatures and times there was a difference between control and treated fruit, but no pattern was evident. It is very doubtful that the use of hot water can be an acceptable alternative to MeBr to treat cherries to meet export requirements. Quality attributes of cherries are extremely reduced when the fruit is exposed to hot water, at various temperatures, and these temperatures are much less than what is required to eliminate the insect in question.

In the double baths, fruit color (*L* and hue) of 'Lapins' and 'Sweetheart' sweet cherries was not influenced by heat treatment, regardless of the time or temperature (Table 3), but visual color of both 'Lapins' and 'Sweetheart' was reduced by heat treatment to an unacceptable level ($>$2.5) at all treatment temperatures and times. 'Rainier' and 'Bing' fruit color darkened (lower *L*-values) for most treatment times and temperatures. Hue color values decreased for 'Rainier' cherries, but increased for 'Bing' cherries, for all treatment times and temperatures, compared with control fruit. Visual fruit color values were also reduced compared with the values for control fruit. Stem color values both (*L* and hue) and visual were unacceptable $>$2.5 at all treatment temperature and time combinations. Stem color loss was much more visible than fruit color changes to treatment and would be critical. Cherry quality is most often assessed on stem color and not fruit color by both fruit brokers and consumers.

Loss of fruit firmness was pronounced, for all cultivars of sweet cherries at all treatment temperature and time combinations (Table 4). Fruit damage (pitting and bruising) was also very conspicuous, regardless of the cultivar, at all treatment temperature and time combinations. There is no doubt that the use of heat, even for short periods of time, influences fruit quality. Fruit exposed to heat, at levels not even close to the levels required to eliminate the insect in question, displayed unacceptable quality.

TABLE 3.
QUALITY FACTORS OF DIFFERENT CULTIVARS OF CHERRIES 14 DAYS AFTER SUBJECTED TO A 40C PRETREATMENT BATH FOLLOWED BY A HOT WATER TREATMENT BATH TO CONTROL CODLING MOTH LARVAE

Cultivar	Treatment		Fruit values			Stem value			Firm	SSC	TA	Pit	Bruise
	Temp. (C)	Time (min)	*L*	Hue	Visual	*L*	Hue	Visual					
Lapin #1	25†	0	21.77	9.77	1.00	30.16	104.88	1.33	4.71	15.93	0.41	6.33	8.67
	50	11	22.06	9.55	2.37**	22.23**	69.88**	3.50**	4.74	15.37	0.40	32.67**	34.33**
	52	7	22.11	9.71	2.73**	20.86**	70.73**	3.80**	4.28	15.27	0.41	36.33**	39.33**
	54	2	22.25	10.33	2.30**	22.83**	66.63**	4.00**	3.65*	15.07*	0.38	29.67**	40.00**
Rainier #1	25	0	62.91	83.37	1.00	27.44	100.83	1.00	5.58	17.77	0.53	3.67	6.00
	50	11	56.52**	73.59*	1.57**	25.33	93.76	2.47**	4.45**	18.43	0.52	25.67**	33.00**
	52	7	57.50*	73.74*	1.60**	24.48	84.44**	2.53**	4.63**	18.33	0.52	32.33**	27.00**
	54	2	58.37	75.68	1.57	25.22	78.76**	3.23**	4.56*	17.87	0.51	29.33**	33.67**
Rainier #2	25	0	52.46	50.64	1.93	27.55	76.67	2.20	5.54	19.23	0.40	18.33	21.67
	50	11	44.87*	48.15	3.20**	23.85	76.20	3.60**	4.26**	19.00	0.38	26.00*	40.00**
	52	7	49.02	55.21	3.40**	23.50	70.19	4.00**	4.18**	18.40	0.39	31.33**	40.00**
	54	2	47.94*	51.12	2.90**	21.57*	72.01	3.60**	4.65**	17.73*	0.38	29.67**	36.33**
Sweetheart	25	0	23.40	10.40	2.00	32.97	101.64	2.17	5.92	20.40	0.69	12.33	0.67
	50	11	22.87	9.92	3.50**	26.09*	81.32*	3.17*	5.73	22.03*	0.64	40.33**	2.00
	52	7	23.50	10.50	3.00**	25.81**	77.33**	3.17*	5.49*	21.87	0.65	37.67**	2.33
	54	2	24.17*	10.81	3.00**	31.21	95.30	3.00**	4.95*	21.20	0.69	43.00**	13.00**

Significant differences from control on day of observation: * $P < 0.05$, ** $P < 0.01$.
† Control.
Temp., temperature; SSC, soluble solids content; TA, titratable acidity.

TABLE 4.
QUALITY FACTORS OF ‘BING’ CHERRIES 14 DAYS AFTER SUBJECTED TO A 40C PRETREATMENT BATH FOLLOWED BY A HOT WATER TREATMENT BATH TO CONTROL CODLING MOTH LARVAE

Treatment		Fruit values			Stem value			Firm	SSC	TA	Pit	Bruise
Temp. (C)	Time (min)	*L*	Hue	Visual	*L*	Visual	Hue					
	0†	27.21	15.09	2.50	26.86	101.60	1.33	4.27	20.50	0.86	27.0	24.00
46	5	26.32*	16.01*	3.00**	28.23	97.69	2.00*	2.52**	19.30**	0.76*	4.33**	26.00
46	7	25.86**	17.00	3.50**	27.59	99.36**	2.17*	2.26**	19.07*	0.75*	3.00**	22.67
48	0	27.50	16.65**	2.50	27.78	98.90	2.33*	3.32	18.57**	0.78	19.33	28.67
48	3	25.81*	17.16**	3.00**	26.75	98.35*	2.50**	2.48**	18.47**	0.75**	12.67*	28.67*
48	5	26.02*	16.49**	3.00**	27.20	98.29**	2.33*	2.34**	18.80**	0.75*	12.00**	12.67**
50	0	26.07*	16.48**	3.00**	26.37	94.65**	2.00*	2.48**	19.50*	0.76*	10.67**	16.67
50	3	26.20	16.88**	2.83	26.38	95.24**	1.83	2.42*	18.97*	0.80	9.67**	17.67

Significant differences from control on day of observation: * $P < 0.05$, ** $P < 0.01$.
† Control.
Temp., temperature; SSC, soluble solids content; TA, titratable acidity.

DISCUSSION

'Bing' cherries are in major demand as an export product, and the request for 'Sweetheart' cherries to be exported is on the increase. Neither of these cultivars maintain acceptable quality after exposure to hot water even for short periods of time. After only 5 days, quality of either cultivar was less than acceptable regardless of water temperature or time of exposure. All time and temperatures used that resulted in quality loss were far below the thermal death curve of the codling moth. After 14 days of storage quality deterioration was even more evident, particularly for the 'Sweetheart' cultivar. Hot water is not a suitable alternative to MeBr to meet quarantine requirements for export, even with a pretreatment bath for temperature conditioning. Other research (Feng *et al.* 2004) has indicated that hot water may be acceptable as a quarantine treatment, if storage time after treatment is limited to only 5 days. In our study, quality was not acceptable, regardless of storage time, and not acceptable with two cultivars of cherries.

Our study differed from that of Feng *et al.* (2004) in several capacities, which may explain their limited success in using hot water treatments. Ecologically, the growing areas in California are warmer and the fruiting season earlier so that the fruits may be preconditioned before exposed to hot water. Morphologically, these fruits tend to be smaller than those from the Pacific Northwest. In our study, we included 'Sweetheart,' a late season cultivar that was excluded in the Feng *et al.*'s study. Finally, we placed greater emphasis on stem quality, an important marketing fruit characteristic. If the same level was applied to the California fruits, they may not have been acceptable.

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Mention of a proprietary product does not constitute an endorsement or recommendation by the UDSA for its use.

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